ENVIRONMENTAL REMOTE SENSING FOR MONITORING PLANT HEALTH

TECHNOLOGY NEED

There is a current and future need to monitor DOE sites:

- To pinpoint existing contamination in soil/groundwater for later cleanup.
- To periodically monitor contained sites for possible leakage.
- To demonstrate cleanliness of remediated sites.
- To detect changes and for stewardship of lands.

Because of the large areas of land involved, some of which are not easily accessible, monitoring based on remote sensing techniques is more cost-effective. Remote sensing data coupled with ground truth data have been shown to be a cost-effective way to eliminate the need for detailed point sampling of large areas of non-contaminated land. Remote sensing, however, has been limited by the lack of data available for using vegetation cover as an indicator of subsurface and surface contamination. This work is focused on understanding the phenomenological origins of the changes in vegetation. To understand the causes of the observed changes, more than the traditional remote sensing tools have been used to collect the data needed to develop an understanding of plant health changes. Laser-induced fluorescence was chosen to complement existing passive techniques because fluorescence from plants has been shown to be altered by stresses such as metal contamination. The approach in the work is to develop active remote sensing technology specifically for plants, and compare the technology to passive techniques in an effort to understand the origin of these plant-based signatures.

A few specific examples of Site Technology Coordination Groups (STCG) needs are:

- AL-07-09-03-SC:.Long-term surveillance and maintenance program at several facilities; e.g., evaluate the consequences of biointrusion at Uranium Mill Tailings Remedial Action (UMTRA) sites.
- AL-07-06-01-SC:.Locate chromium (Cr) contamination at the Pantex plant: “In-field characterization technology to quickly identify and delineate contaminated areas.”
- AL-07-01-01-SC:.Identify helium (He) and barium (Ba) hot spots for cleanup at Los Alamos National Laboratory.
- NV-18-9801-05:.Nevada Test Site: Efficient monitoring systems to monitor.plant root penetration and contaminant uptake.
- SR-3025:.Savannah River Site:.Monitoring integrity of contained waste sites.

No comparable baseline technology currently exists for surveying large areas for minor to moderately severe subsurface contamination. Passive remote sensing can see only very severe problems. Unless the contamination is extremely heavy, surveys for subsurface contamination most often rely on spot checks using groundwater or soil sampling techniques generally requiring laboratory analyses); this makes large-area ground surveys very labor intensive and, therefore, difficult and expensive. A faster, cheaper technique is needed.

TECHNOLOGY DESCRIPTION

The technology uses remotely sensed optical signatures from vegetation as an indicator of contamination in the soil or groundwater. In addition to passive reflectance as a baseline, laser-based technology is being developed as a more chemically sensitive optical probe. A pulsed ultraviolet laser is used to excite fluorescence in the vegetation being surveyed. The fluorescence is collected spectrally in the 400 to 800-nm region. Data collection can be done in full daylight. Sensor standoff can be anywhere from a few feet to hundreds of feet; the sensor system could even be used on a low-altitude airborne platform. The data collected are analyzed for indications of stress in the plants that may signify an environmental problem (change detection) such as subsurface contamination.

BENEFITS

This technology will allow faster, cheaper, and less labor-intensive surveys of large areas (by ground or air) with more complete ground coverage. Remote sensing with laser-induced fluorescence makes it feasible to monitor contained sites regularly at reasonable costs. Remote sensing allows better access for certain difficult-to-reach areas (e.g., swampy areas), and reduces or eliminates the time that must be spent by workers in dangerous and/or contaminated zones. This technology also eliminates the need to handle soil or water samples (perhaps contaminated with other things than the expected contaminants) unless indicated for ground truth verification. In summary, the technology being developed will be faster, lower cost, lower risk, than point sampling techniques. It will allow surveys of areas not easily accessible and provide more complete coverage data than point sampling. The technology being developed will also become the baseline technology for environmental surveys where no comparable baseline technology presently exists.

CAPABILITIES/LIMITATIONS

The primary limitation of the technique being developed is the lack of laser-induced fluorescence plant health and stress data needed to identify contaminant stress in plants. It is not currently known what the technique can and cannot be expected to do in the field, since tests to date have been limited primarily to the laboratory. This technology should be effective in soils to depths limited only by penetration depth of roots. It is not currently known how specific the technique can be made (e.g., Can it differentiate between specific contaminants?). This will depend partly on the results of current investigations of several data-analysis methodologies, as well as the outcome of new research indicating that it may be possible to code plants to be responsive to specific contaminants.

COLLABORATION/TECHNOLOGY TRANSFER

Current collaborations are:

- Walt Disney World/Epcot Center:.Collaboration/in-kind support including greenhouse space, office space, temperature-controlled labs and chambers, laboratory equipment, consumables budget, and 5 to 10 percent time-use of a plant nutritionist, entomologist, pathologist, technician, horticulturist, engineer, and secretary.
- National Aeronautics and Space Administration (NASA)/Kennedy Space Center and Dynamac Corp:.Collaboration and in-kind support including laboratory space and use of equipment (HPLC, spectroradiometer, pyranometer, microscopes, histology microtome and staining system, balances, etc.), consumables budget, and some personnel support (leaf histology and biochemistry).
- Georgia State University:.Visible/near infrared (NIR) imaging system brought to group data-takes at Epcot with subsequent sharing of information.
- NASA/Stennis, LA:.Hyperspectral imaging equipment brought to group data-takes for measurements, with subsequent sharing of information.
- Kansas State University:.Plant physiology and leaf biochemistry.
- Florida Institute of Technology:.Advanced data analysis.
- Citrus Research Education Center (University of Florida):.Plant viruses and tagging plants with green fluorescent protein (gfp).
- Army Corps of Engineers, Topographic Engineering Center, VA: Hyperspectral and fluorescence data fusion studies.

The Savannah River Site has also expressed an interest, and we are planning an on-site demonstration there, perhaps beginning as soon as this fiscal year. Interest about commercial applications has been expressed only through inquiries. There has been no concrete action so far. Interested commercial entities include:

- Walt Disney World Company:.Measuring stress in transplanted mature trees.
- Weyerhauser Corporation:.Monitoring of timber producing forests.

ACCOMPLISHMENTS

A Memorandum of Understanding (MOU) was initially signed between DOE and Disney and is still in effect. Following this, a plant measurement laboratory was established at The Land, Epcot, with a full-time on-site plant scientist and technical support. The laboratory has been outfitted with much state-of-the-art instrumentation, plus custom instrumentation built by STL, including a multi-axis robot on a 5-meter track, installed in the greenhouse and integrated with a suite of three sensors for automated data collection. A laser-induced fluorescence imaging (LIFI) system was modified for plant measurements and a laser-induced fluorescence spectroscopy (LIFS) system was built and added to it; this portable system is used at Epcot and other locations including Poland. With the customized and evolving instrumentation, the on-site plant expertise, and the ever-growing number of collaborators from government and academia, the facility at Epcot is becoming a world-class plant measurement facility, specifically in support of finding remote sensing solutions for certain DOE problems.

Specific accomplishments for first half of FY 1998 include:

<u>Demonstrations:</u>

The first group field data-take occurred at Epcot in March 1998 on baseline and zinc-stressed beans, wheat, and Bahia grass plants. This group data-take included not only measurements using DOE equipment stationed at Epcot, but also LIFI/LIFS measurements, as well as measurements with instrumentation brought by Georgia State University and NASA/Stennis. The idea is to compare results of all sensors to gain a better understanding of the plants and (primarily) to help identify what are the best signatures for quantifying plant stress. The data looks good, but analysis is not complete.

<u>LIFI/LIFS System Development:</u>

- Developed new software written for data handling with separate programs for post-processing images and spectra.
- Built new expanded-capability optical input heads for LIFS with simultaneous collection of spectra at three different fields of view.
- Calibrated the LIFS system intensity.
- Built a Laser-Induced Breakdown Spectroscopy (LIBS) capability into the system which has not yet been tested.
- Began redesign for a smaller, more rugged, and more user-friendly system.

<u>Robotic System at Epcot Development:</u>

- Designed/built hardware for selectable field of view.
- Replaced the reflectance spectrometer with a new device for a 10-fold increase in sensitivity.
- Rewrote software that controls the three-sensor experiment for better performance.
- Performed absolute system intensity calibration.
- Began work on second spectrometer channel plus associated custom software to record changes in ambient light (using a Spectralon target).
- Began to take actual data with Robot system for baseline plant database.
- Started work with more sophisticated spectral data analysis techniques, including neural net analysis and higher order derivative analysis.
- Beginning to look into green fluorescent protein (gfp) technology (Used LIFI/LIFS to examine some plants with green fluorescent protein (gfp-tagged virus).
- Completed the required zinc stress experiments on beans and compiled the required report, but because of interesting results, the experiments on beans are being extended through June. Wheat a monocot, has also been added to the experiment.
- Began to examine the effects of zinc on Bahia grass (Bahia grass grows on some of the clay cap covers at Savannah River Site); we are preparing to grow loblolly pine, another plant that grows at DOE sites.

TECHNICAL TASK PLAN (TTP) INFORMATION

TTP No./Title: NVO-5-C2-21 - Environmental Remote Sensing for Monitoring Plant Health

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Excitation emission spectra of several kinds of healthy plants were acquired with Laser-Induced Breakdown Spectroscopy (LIBS)